Studies of Ionospheric Irregularities: Origins and Effects

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LONG-TERM GOALS

We have two long-term goals. The first goal is to understand the electrical properties of the upper atmosphere and space environment to better assist designers and users of space systems and technology. The second goal is to educate the next generation of leaders in space science and engineering.

OBJECTIVES

The scientific objectives of the project are to:

(1) Develop GPS receivers for measuring scintillations and scintillation effects on GPS signals and receivers;

(2) Investigate the effects of equatorial scintillation storms on GPS through field campaigns and deployment of GPS scintillation receivers at collaborating institutions in South America and globally;

(3) Develop space-based GPS receivers for sounding rocket and satellite applications;

(4) Investigate the role of plasma waves in accelerating particles (transverse ion acceleration) and in providing a mass source for the magnetosphere.

(5) Investigate the role of electron phase space holes in particle acceleration and thermalization of space plasmas.

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Our research focuses on the study of waves, irregularities, and wave-particle interactions in space plasmas as well as the effects of these processes on radio signals and energetic plasmas. Our approach is primarily experimental, and we have a reputation for producing cutting edge instrumentation and developing successful experiments. Even though the vast majority of the universe exists in a plasma state, we focus on our own upper atmosphere and ionosphere as natural laboratories for studying space physics and as an environment that affects satellites and their signals. This yields a mix of applied and curiosity-driven research. By primarily employing sounding rockets and ground-based instrumentation, graduate students are able to participate in the full range of research and develop into future leaders. For example, our development of multiple-sensor plasma wave interferometers, beginning with the Viking spacecraft and continuing with sounding rockets, is now a standard feature of ionospheric and magnetospheric missions. During the past several years we developed a GPS scintillation receiver that has been deployed at multiple sites across South America. This receiver not only monitors ionospheric scintillation but additionally measures ionospheric drifts. Furthermore, this effort is currently leveraging our development of space-based GPS receivers. In the next three years we hope it will leverage the development of GPS translators, a world-wide scintillation network, and precision acceleration measurements for measuring neutral atmospheric densities and temperatures.

APPROACH

We are known for developing unique and ground-breaking experiments and instruments. Our most widely known contribution has been the plasma wave interferometer, first developed on sounding rockets and then later included on such spacecraft as Viking, Freja, Polar, Fast, and Cluster. Another example of new instrumentation developed at Cornell is the intelligent snapshot receiver, which is now popular among many groups and was part of the Freja plasma wave experiment. More recently we have developed GPS receivers, both for making scintillation measurements and for providing time transfer capability on spacecraft.

Our scientific strategy emphasizes experimental development. We have chosen this route because the field of space science, especially the electrical properties of space, is still experimentally limited. Theories of space physics and space plasma physics are quite plentiful, but discriminating measurements are few and far between. Within this context one may well ask what areas need the most attention. The answer concerns nonlinear problems involving plasma waves and electric fields in collisionless environments and turbulent media. Incidentally, these areas are also examples that, at one extreme, can test theories of basic plasma physics and, at the other extreme, are important for the development and application of new communication and navigation technologies.

The logistics and operational challenges of ground-based experimentation are relatively new developments in our experimental program since most of our previous work was with space-based experiments. Since we lack the infrastructure to develop our own ground-based measurement program, we have created a new vision or “business plan” for obtaining ground-based measurements. We give GPS receivers away “free” to collaborators who then operate the receivers in regions of geophysical interest and share their data with us. This approach has been highly successful and we have established a regional chain of GPS scintillation receivers in South America (mostly Brazil) from the equatorial anomaly to the geomagnetic equator. Our next effort is to expand this strategy globally; we have already identified collaborators in Argentina, Australia, Eritrea, Italy, India, and Nigeria.

WORK COMPLETED

(1) Completed a 3-month campaign of obtaining GPS scintillation measurements with 5 receivers on a 700 m by 1000 m grid.

(2) Developed a GPS L1 phase scintillation receiver and operated it under the equatorial anomaly.

(3) Developed and fabricated a sounding rocket “class” GPS receiver and conducted one test flight from NASA/WFF.

(4) Began analysis of Cluster wideband electric field data and identified the existence of electron phase space holes in the bow shock transition region.

RESULTS

In addition to the normal operation of our GPS receivers in South America we conducted a special three month campaign in Cachoeira Paulista, Brazil, under the equatorial anomaly, to understand and parameterize the spatial and temporal characteristics of GPS L1 scintillations. This campaign produced 100 GB of data which we are transferring to hard disk drives for analysis. From this campaign we have three initial results. We have demonstrated the north-south coherence of scintillations. We have shown that the north-south elongations are tilted depending on satellite azimuth, elevation, and magnetic dip angle. Finally, we have made the first measurements of L1 phase in the disturbed equatorial ionosphere.

The shape of scintillation fades is important in understanding the potential effect of scintillation on moving GPS receivers. Using 3 GPS receivers aligned in the north-south direction with up to 990 m separation we demonstrated that fades are greatly elongated in the north-south direction. In fact, at 990 meter separation we could detect no change or loss of coherence, implying that L1 fades extend much farther than 1 km in the north-south direction. The implication of this “discovery” is that moving GPS receivers need only match the east-west drift velocity of the fading pattern to be in resonance. The north-south velocity does not contribute to breaking resonance.

Next we made a discovery that slightly modifies the previous paragraph. The elongated north-south fades are tilted with respect to geomagnetic north and the tilt angle depends on the satellite azimuth and elevation as well as the magnetic dip angle. Figure 1 demonstrates a comparison between predicted and measured tilt angle. If our geometric estimate of the tilt angle and our measurements of the tilt angle were both perfect, all of the crosses would lie on the straight line. This preliminary analysis suggests that the fit is reasonably good and we will continue to examine more data to study this effect.

Next we made the first measurements of GPS L1 phase scintillations. The Cornell University GPS scintillation receiver was modified with a stable phase source or oscillator and a phase lock loop for tracking. This phase reference was adequate to measure the effect of the disturbed equatorial ionosphere and spread-F on the phase of GPS L1 signals. Figure 2 shows an example of simultaneous amplitude and phase scintillations during the onset of an equatorial spread-F event. The amplitude scintillations begin at about 400 s from the start of the data set but the phase scintillations begin somewhat sooner, about 200 s from the start of the data set. One should note that these phase

scintillations are primarily produced by changes in total electron content (TEC) and not by diffraction, which produces the amplitude scintillations. The phase scintillation amplitude and dynamics are quite serious and a few hundred seconds after the end of this data set the GPS receiver failed to successfully track the signal because of the fast dynamics. We will be examining more of these data to understand the effects of phase scintillation on GPS receiver operation.

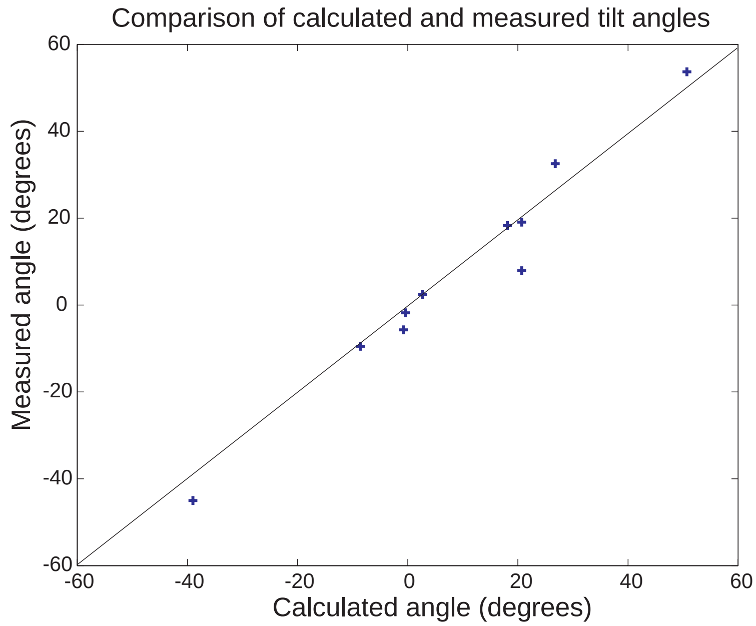

Figure 1. A comparison of measured and calculated GPS scintillation tilt angles. A simple "picket fence" interpretation would imply that all points would lie on the straight line.

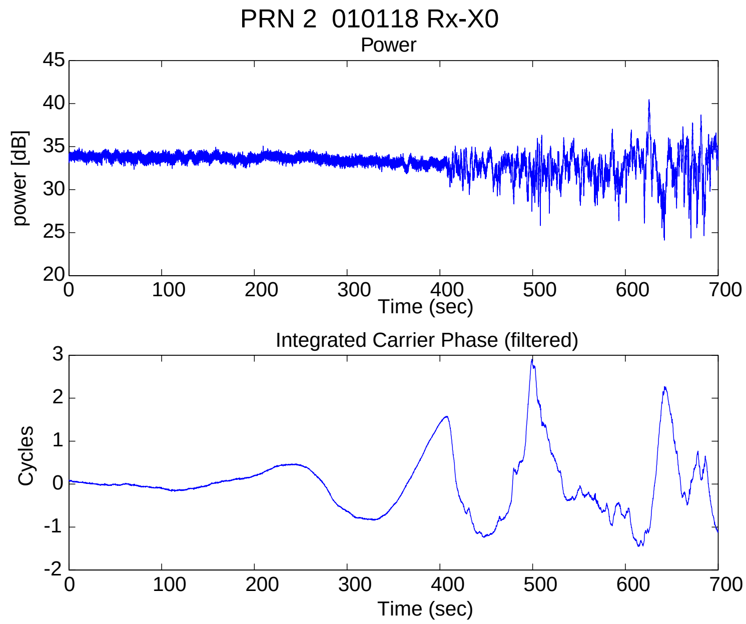

Figure 2. GPS L1 signal scintillations. Amplitude scintillations are shown in the top panel and phase scintillations are shown in the bottom panel.

In addition to work with GPS we made some preliminary, but very interesting, discoveries with the Cluster wideband electric field data, showing the existence of electron phase space holes (EPSH). These data are provided to us through the University of Iowa and Don Gurnett. EPSH are interesting objects because until several years ago their existence was unknown and now they are found in virtually all collisionless plasmas that are not in equilibrium. This phenomenon has nearly universal importance but was unknown in space a decade ago, primarily because plasma wave receivers were designed to observe in the frequency domain. The EPSH is a nonlinear object requiring observation in the time domain. Previously we had studied EPSH using Polar data in the plasma sheet and cusp. With the Cluster data we can now study EPSH in more environments. Figure 3 shows an example of EPSH in the shock transition region. The bipolar spikes are individual EPSH crossing the electric field antenna. Our continued analysis will depend on acquiring magnetic field and electron data, which we will work with the University of Iowa and the Swedish Institute of Space Physics at Uppsala to accomplish.

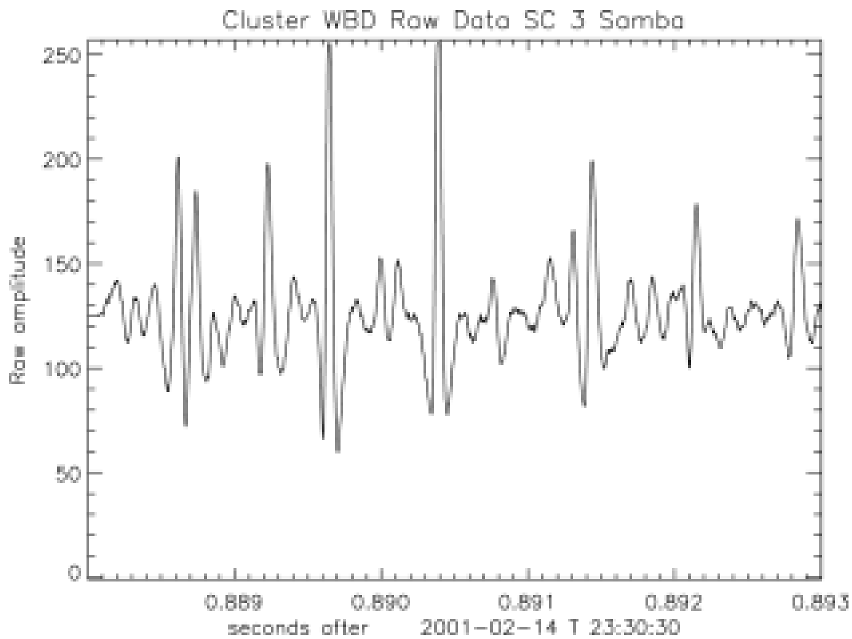

Figure 3. Examples of electron phase space holes observed by the Cluster satellite in the bow shock transition region.

IMPACT/APPLICATIONS

Our work with GPS receivers and measurement of scintillations continues to be important in understanding and predicting the behavior of GPS receivers in the presence of scintillations. Determining the shape of fade patterns is important to understanding how velocity resonance will occur and potentially produce loss of lock or even loss of navigation in GPS receivers. We will be using the same data set to understand the temporal scales of scintillations in their moving reference frame to establish an upper limit on fade length or time scale in the velocity matching reference frame. Next our work with L1 phase scintillations suggests that receivers using the phase observable are even more vulnerable to scintillations than receivers using just code range.

TRANSITIONS

We are planning toward three major transitions in the next year. First, we hope to establish a truly global chain of GPS scintillation receivers in Argentina, Australia, Eritrea, Italy, India, and Nigeria, as discussed earlier. We will be looking for more collaborators willing to join us. Second, with a DURIP grant we were able to purchase a GPS signal simulator that can simulate L1 amplitude and phase scintillations. We will begin a program of using measured scintillation activity to program the simulator and explore amplitude and temporal scales and their effect on GPS receiver reliability.

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